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Effects of fire on soil microarthropods of a phryganic ecosystem

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Summary. The effects of a wild fire on soil microarthropods were studied in a Phryganic ecosystem of Greece. In the control site, the abundance of soil microarthropods showed considerable spatial and temporal variations. It was greater: In the space around individual shrubs where the organic layer was well developed than under the surface stones where a small amount of organic material was trapped. During the rainy season of the year rather than the dry season when most soil microarthropods were not active in the upper soil layers. The second than the first year of the study. This refers mainly to Acari, which maintained high population densities in spring of the second year (rainy season) in contrast to the same season of the first year which was exceptionally dry. Due to fire, the abundance of most populations was significantly reduced in the space around the shrubs. The magnitude of this reduction was comparable to the between microsites variation observed in the unburnt site. Under the stones the abundance of soil microarthropods was not affected or it was increased due to fire. As a consequence, the magnitude of the spatial and seasonal variations in the burnt site was comparatively low. Different taxa were affected differently by the fire or they exhibit differences regarding their recovery. Overall, the recovery time for most taxa is estimated to be less than 3–4 years.

Key words: Greece, Wild-Fire, Cryptostigmata, Collembola

Introduction

Phrygana (synonym of coastal sage – California, tomilares – Spain, batha – Israel) is a Mediterranean type formation, occupying the dry end of the precipitation gradient of Mediterranean climate regions. The vegetation is dominated by aromatic or thorny shrubs characterized by seasonal dimorphism of their leaves (Margaris & Vokou 1982).
Phrygana covers approximately 13% of Greece (Diamantopoulos 1983). The vegetation is flammable and in certain localities it is burnt accidently or on purpose every 3 to 5 years (Papanastasis 1977). The post fire recovery pattern of phryganic vegetation is similar to that observed in other regions with mediterranean-type climate. Fire stimulates the germination of herbaceous and of a few woody species, e. g. *Cistus* spp. Most of the woody plants regenerate by resprouting. The early stages of post fire succession are characterized by the dominance of herbaceous plants (Papanastasis 1977, Arianoutsou-Faraggitaki 1984). Later on, the resprouting shrubs take over and after six to seven years the vegetation structure becomes similar to that of the prefire period (Arianoutsou-Faraggitaki 1984).
Little information is available regarding the soil fauna of phrygana (Sgardelis et al. 1981, Magioris 1989). This work is part of a study aiming to describe the effect of a wild fire on the abundance of soil invertebrates.

Materials and methods

Site description

The study site was a gentle hill of about 300 m a.s.l., 50 km SE of Athens (Attiki, Greece). The climate of the area is characterized as semi-arid Mediterranean according to UNESCO-FAO classification (Anonymous 1963).

The vegetation covering the area was destroyed by a wild fire in August 1980. A zone of about 1 km long and of varying width (100 – 500 m) remained unburnt. In this unburnt zone the vegetation was rather dense, dominated by *Genista acanthoclada* Dc. (30%), *Sarcopoterium spinosum* Scop. (15%), *Coridothymus capitatus* (L.) Reichenb. fil (15%) and scattered evergreen shrubs. The litter was restrained around individual plants forming a well determinable layer of about 3 cm thick (O_1). The fermentation layer (O_f) was loose and consisted mainly of macroarthropod excrements. A variable, but always small, amount of organic material was found under the surface stones.

In the burnt site the above ground biomass and the accumulated litter was completely destroyed. In contrast, the organic material under the stones was not affected. A few months after the fire the area was covered by annual plants and geophytes (*Aspodelus aestivus* Brot. dominated in biomass). These plants produced the first amount of litter in the burnt site in late spring (30.4 grm^{-2} compared with 12.5 grm^{-2} produced by annuals in the unburnt site). This litter was spread almost evenly throughout the burnt area.

Climatic data for the period October 1980 – June 1982 are shown in figure 1. The mean monthly temperature displayed the seasonal pattern which is characteristic of the Mediterranean climate. The rainfall showed minimum values in summer and maximum in autumn-winter, as expected. Spring was exceptionally dry in the first year and rather wet in the second.

Sampling

Samples were taken in monthly intervals from October 1980 to April 1982. Supplementary samples were taken in February and April 1983, April 1984 and April 1988. The procedure adopted was the one used by Sgardelis et al. (1981). In each of the two sites (Unburnt and Burnt), microarthropods were sampled in two distinct microsites: the area under the canopy of the dimorphic shrubs, named LT microsite, and the area under the surface stones, named ST microsite. In the burnt site, the LT

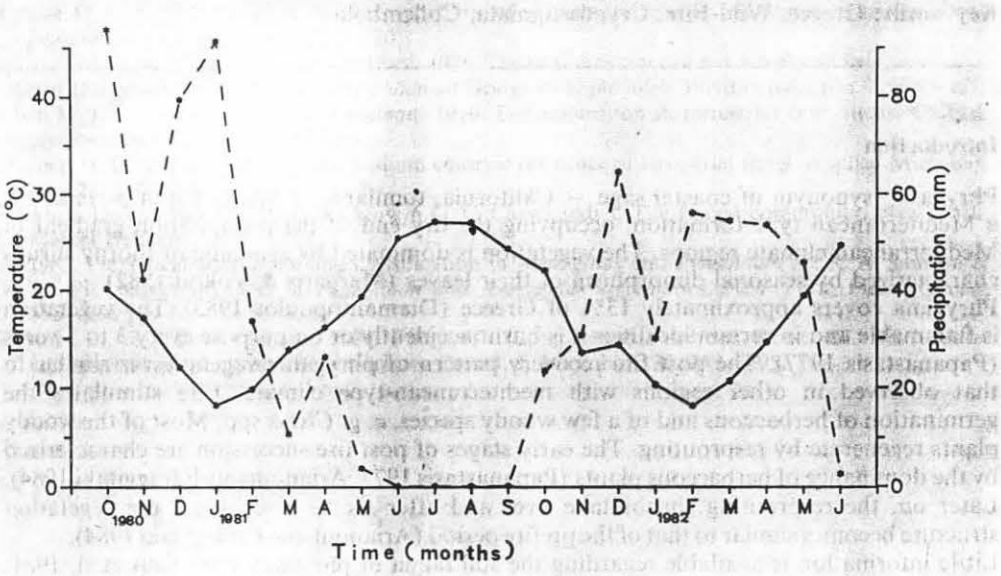

Fig. 1. Mean monthly temperature (°C) and precipitation (mm) variations in the study area. Temperature: ———, Precipitation: – – –.

microsite was determined as the space around the remains of the shrubs, which resprouted a few months after the fire. On each sampling occasion 5 samples were taken from each microsite by a steel cylinder of 20 cm^2 cross section. The samples consisted of the organic horizons and the 3 upper centimetres of the soil. The microarthropods were extracted by means of a modified Berlese-Tullgren apparatus and counted under a stereomicroscope.

Data analysis

Form the sampling schedule adopted, the detected trends of abundance variations of soil microarthropods were the following: Between Burnt and Unburnt sites (effects of fire), Between litter (LT) and stones (ST) microsites (Spatial heterogeneity effect), Between years of study (Interannual trend), Between Wet and Dry seasons of the year (Seasonal trend). Canonical Variate Analysis (C.V.A.) was used to summarize the above trends, separating 12 groups of samples formed a-priori by site (Burnt, Unburnt), microsite (Litter, Stones), year of study and season of the year (Wet, Dry). The one way t-paired test was also used for the comparison between sites, microsites and years of sampling.

Results

Abundance of the main taxa

Estimations of the mean abundances of soil microarthropods are shown in table 1. Acari, and among them Cryptostigmata, as well as Collembola dominated numerically among microarthropods. Cryptostigmata matures and juveniles were represented by almost equal abundances in the Unburnt site. The first year after the fire the number of juveniles was less than a half of that of matures. The following year the juveniles to matures ratio was restored in the LT but not in the ST microsite.

The abundance of most taxa exhibited considerable variation in space (between microsites and sites) and less variation between sampling years. Maximum abundances were recorded in the LT-unburnt microsite and minimum during first post fire year in the LT-burnt microsite. In the LT-unburnt microsite, the abundance of most taxa was intermediate between those recorded in temperate forests and tropical forests or non forested areas (Petersen & Luxton 1982).

Significant differences in soil microarthropod abundances were detected between sites, microsites and years of study (t-paired test).

Variation between sites (effect of fire)

There were considerable differences in microarthropod responses between LT and ST microsites. In the LT microsite, four types of responses were observed. Significant reduction the first post fire year ($P < 0.01$) and no sign of recovery the second year (Cryptostigmata matures and juveniles, *Scheloribates latipes* (C. L. Koch, 1844), *Chamobates* sp., Bdellidae and Mesostigmata except Rhodacaridae). No significant difference the first year followed by significant reduction due to fire the second year (*Hypochthonius* sp., Oppiidae, Rhodacaridae). Significant ($P < 0.01$) reduction the first year, full recovery (Epiedaphic Arthropleona) or recovery tendency (Symphypleona) exhibited the second year. No significant effect at all (Scutacaridae).

In the ST microsite the following response types were observed: No significant effect (Most taxa). Significant increase of abundance the first post fire year, no significant difference the second year *(S. latipes)*. No difference the 1st year. significant increase the 2nd year (Arthropleona Collembola).

Table 1. Mean density* (ind. m^{-2}) of Soil Microarthropods in the two microsites (Litter & Stones) of each site (Unburnt = U & Burnt = B), the first and second year of sampling

	Litter				Stones			
	1st year		2nd year		1st year		2nd year	
	U	B	U	B	U	B	U	B
Cryptostigmata								
Juven.	9635	886	11132	3122	2929	3101	2668	1687
Mature	9777	2699	10195	3223	2673	7771	3035	3293
Total	19412	3585	21327	6345	5602	10872	5703	4980
Juv./Mat.	0.98	0.33	1.09	0.97	1.09	0.4	0.89	0.51
Mature Cryptostigmata								
Oppiidae	2954	1385	3921	1476	1115	1278	1395	1991
S. latipes	4148	270	2585	397	759	5291	989	504
Chamobates sp.	433	26	927	153	153	87	127	112
Hypochthonius sp.	728	754	1838	713	204	117	229	219
Carabodes sp.	153	110	103	229	118	240	71	215
Damaeus sp.	142	36	112	0	76	137	10	148
Galumnidae	244	36	127	92	41	137	56	80
Nothroidea	102	73	190	26	41	25	20	10
Pelopidae	25	0	0	36	66	25	118	0
Liodidae	120	0	18	0	10	10	0	9
Phthiracaridae	36	0	140	0	10	0	20	5
Liacaridae	78	0	42	0	10	0	0	0
Prostigmata								
Bdellidae	1461	290	1874	433	331	1044	530	1390
Scutacaridae	66	16	4089	2903	61	204	1130	1665
Other	5942	2885	13871	3855	1566	1408	2570	2738
Total	7469	3191	19834	7191	1958	2656	4230	5793
Mesostigmata								
Rhodacaridae	316	305	840	560	163	290	417	473
Other	4216	688	3718	611	1950	2519	1378	1407
Total	4532	993	4558	1171	2113	2809	1795	1880
Collembola								
Arthropleona								
Euedaphic	10628	1538	8316	3524	2368	3819	2536	3794
Epiedaphic	3616	255	2852	3055	1808	1451	693	1747
Symphypleona	677	36	1080	280	367	87	474	61
Total	14921	1829	12248	6859	4543	5357	3703	5602
Diplopoda								
Iulida	17	0	46	18	17	17	0	0
Polydesmida	42	42	9	0	0	230	0	0
Polyxenida	25	8	92	0	25	25	0	0
Total	85	51	65	18	42	272	0	0

Table 1. (continued)

	Litter				Stones			
	1st year		2nd year		1st year		2nd year	
	U	B	U	B	U	B	U	B
Insects (Larvae)	647	76	407	153	305	163	295	97
Protura	244	117	163	188	255	112	193	163
Thysanoptera	25	76	15	66	117	15	112	10
Embioptera	142	10	417	36	36	15	36	10
Symphyla	204	117	168	203	51	112	102	306
Pseudoscorpiones	204	10	168	41	397	87	280	356

* Values rounded to the nearest integer.

Variation between microsites (Spatial heterogeneity effect)

In the unburnt site, the abundance of soil microarthropods was significantly greater in the LT than the ST microsite. After the fire the abundance of most taxa was not different or it was significantly greater in the ST microsite (Cryptostigmata matures and juveniles, *S. latipes*, Arthropleona Collembola and Mesostigmata except Rhodacaridae).

Variation between years of study

In the unburnt site, the abundance of most taxa increased in the second year of the study. In the case of *Hypochthonius* sp., Scutacaridae, and Rhodacaridae this interannual trend was significant. In the burnt site, significant interannual trends were exhibited by mature Cryptostigmata, Prostigmata, epiedaphic Arthropleona and Symphypleona within the LT microsite and by Prostigmata within the ST microsite. In the latter microsite, the abundance of Cryptostigmata and especially that of *S. latipes* was significantly decreased the second year after the fire.

The above trends are summarized in the plane of the two first axes of C.V.A. Acari (Fig. 2a) were treated separately from the other taxa (Fig. 2b). In the case of Acari the first axis accounts for 66% and the second for 13% of the between to within group variation. The first axis separates mainly the LT microsite groups by -in order of magnitude-, season, site and year of study. Referring to the study year, the separation is clear cut concerning the unburnt but not the burnt site. Thus, the slight post fire recovery trend is obscured by the much wider interannual trend of abundance increase exhibited in the unburnt site. As a result, the separation between sites appears to be wider the second than the first year after the fire. The main discriminators are Cryptostigmata juveniles associated with the LT-Unburnt-Wet group and *Carabodes* sp. associated with the Dry samples. The second axis separates the sampling years and especially the ST-Burnt-Wet-1st year samples, characterized by the dominance of *S. latipes*.

In the case of the other microarthropods the first axis accounts for 52% and the second for 20% of the total separation of the groups. As with Acari, the first axis accounts mainly for the separation of the Litter microsite groups, by season, site and year of study. However, the separation between years in the unburnt site is not important while that concerning the burnt one is considerable. The main discriminators are Collembola and Isopoda associated with the Unburnt-Litter-Wet groups and Embioptera associated with the Dry period Groups. The second axis accounts for the separation of study years as well as for the effects of fire in the ST microsite.

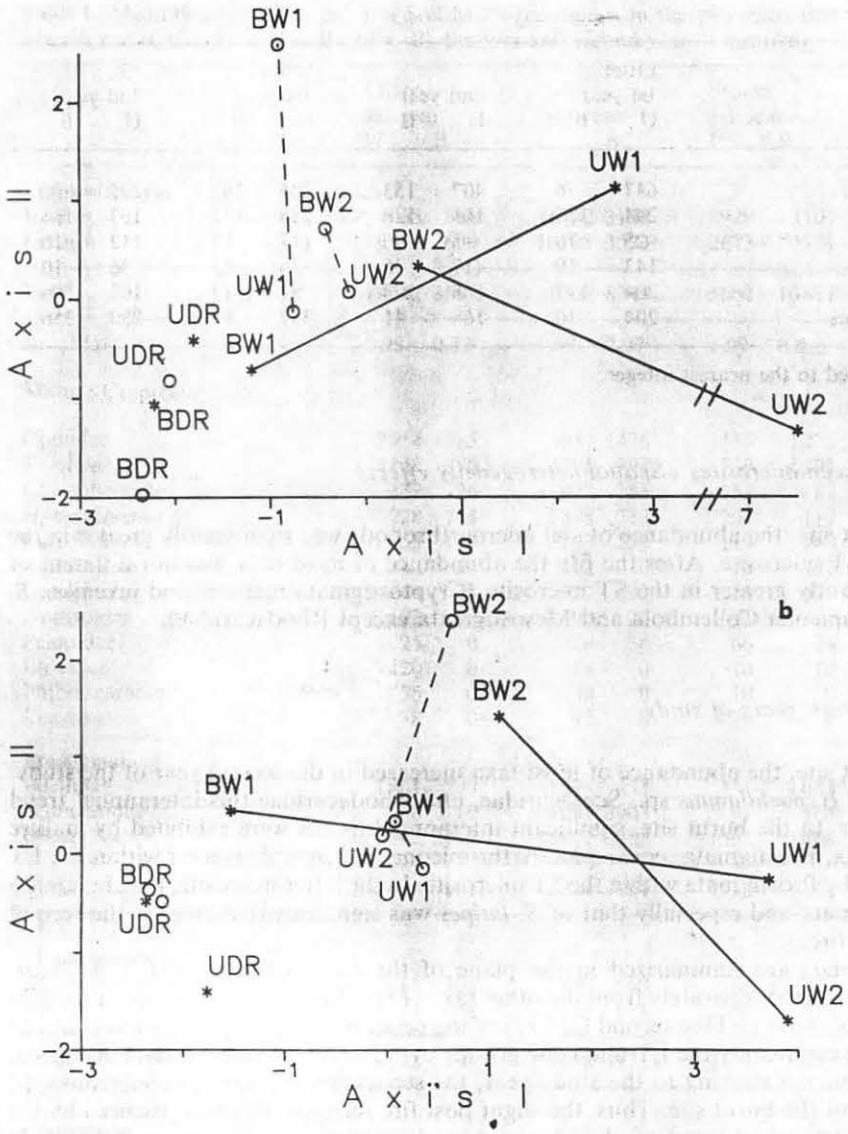

Fig. 2a, b. Canonical Variate Analysis first two axes for the discrimination of samples grouped by site (U = unburnt, B = burnt), microsite (* = Litter, O = Stones), season (W = wet, DR = dry) and year (1 = first, 2 = second) of study. Only group centroids are graphed. For convenience, the width of the fire's effects are indicated by line segments connecting the appropriate group centroids of each microsite (Litter = solid line and Stones = dashed line). a) Analysis based on the abundances of 16 taxa of Acari, b) Analysis based on the abundances of 13 taxa of other microarthropods.

By means of the above results, the main trends of soil microarhtropod abundance variations can be summarized as follows: Seasonal trend: This trend characterizes mainly the fauna inhabiting the LT microsite. The abundance of most soil microarthropods exhibited maximum values during the wet period of the year. Only *Carabodes* sp. among Acari and Embioptera among the other microarthropods appeared to resist drought and thus they dominated the fauna in summer. Effects of fire: Most taxa were highly affected by the fire in the LT microsite. The separation of sites appears to be as wide as the seasonal trend

recorded in the LT-unburnt microsite and of the same direction as the latter. Considering the ST microsite, the effects of fire are accounted for on the second axis of C.V.A., due to the fact that the abundance of some taxa was positively affected by fire (*S. latipes* the first year and Collembola the second one). Interannual trends: The abundance of most Acari (except *S. latipes*) was greater the second year of the study in the LT-unburnt microsite. In the LT-burnt microsite this interannual trend (which can be considered as a recovery trend) was less wide. The reverse happened regarding the other microarthropods, which exhibited a considerable recovery trend. In the ST microsite the interannual trend was less important.

Long term recovery after fire

The percentage difference of abundances (PD%) between the unburnt site (U) and the burnt site (B) was used as a simple descriptor of the long term recovery trends:

$$PD\% = (B - U) \times 100/(B + U).$$

In figure 3 (a–f) are shown the oscillations of the monthly estimations of PD% values regarding, euedaphic (Fig. 3a) and epiedaphic Collembola (Fig. 3b), Cryptostigmata matures (Fig. 3c) and juveniles (Fig. 3d), Prostigmata (Fig. 3e) and Mesostigmata (Fig. 3f).
In all the cases, the PD% values estimated for the LT microsite tend to approach zero (recovery of the populations) in the long term. In the ST microsite, PD% values oscillate widely around zero but there are distinct periods characterized by positive values. In general it can be said that the recovery time of Acari is less than 30 months. In the case of Collembola it seems that after an initial recovery tendency observed the second year, PD% values tend to decrease in February and April 1983. Thus, the recovery time of Collembola is estimated to be more than 30 months. It must be noted, however, that the use of PD% values for the estimation of the recovery time is not satisfactory. The point is that PD% values exhibit considerable monthly oscillations the first two years of the study. Thus, the once per year sampling program, adopted after 1983, hardly characterizes the overall situation.

Discussion

Taking into account the population density of most taxa of soil microarthropods in the LT-unburnt microsite, the study area occupies a position between temperate forests and non forested areas. An analogous conclusion has been drawn by Asikidis & Stamou (1991) concerning an evergreen-mediterranean formation of Northern Greece. According to Di Castri & Vitaly-Di Castri (1981) this is expected for most Mediterranean type ecosystems.
A common aspect of the vegetation in the Mediterranean type shrublands of Greece is the patchy distribution of the shrubs and of the litter they tend to retain under their canopies. Thus, litter accumulations form more or less isolated and protected microsites, where the soil invertebrates aggregate (Sgardelis et al. 1981, Magioris 1989, Asikidis & Stamou 1991, present study). A small portion of the populations inhabit the space under the surface stones (Sgardelis et al. 1981, Magioris 1989, present study) or the exposed soil (Asikidis & Stamou 1991). Thus, the spatial pattern of microarthropod abundance variations could be related to the uneven spatial distribution of the litter and finally to the patchy distribution of the shrubs. The dependence of the abundance of soil animals on the amount of litter has been stated frequently (see for example Garay et al., 1980, Sharma et al. 1984, Kaneko 1985, Cepeda-Pizarro & Whitford 1989, Asikidis & Stamou 1991). It is also well documented that soil animals, and especially Acari and Collembola, inhabit the uppermost organic

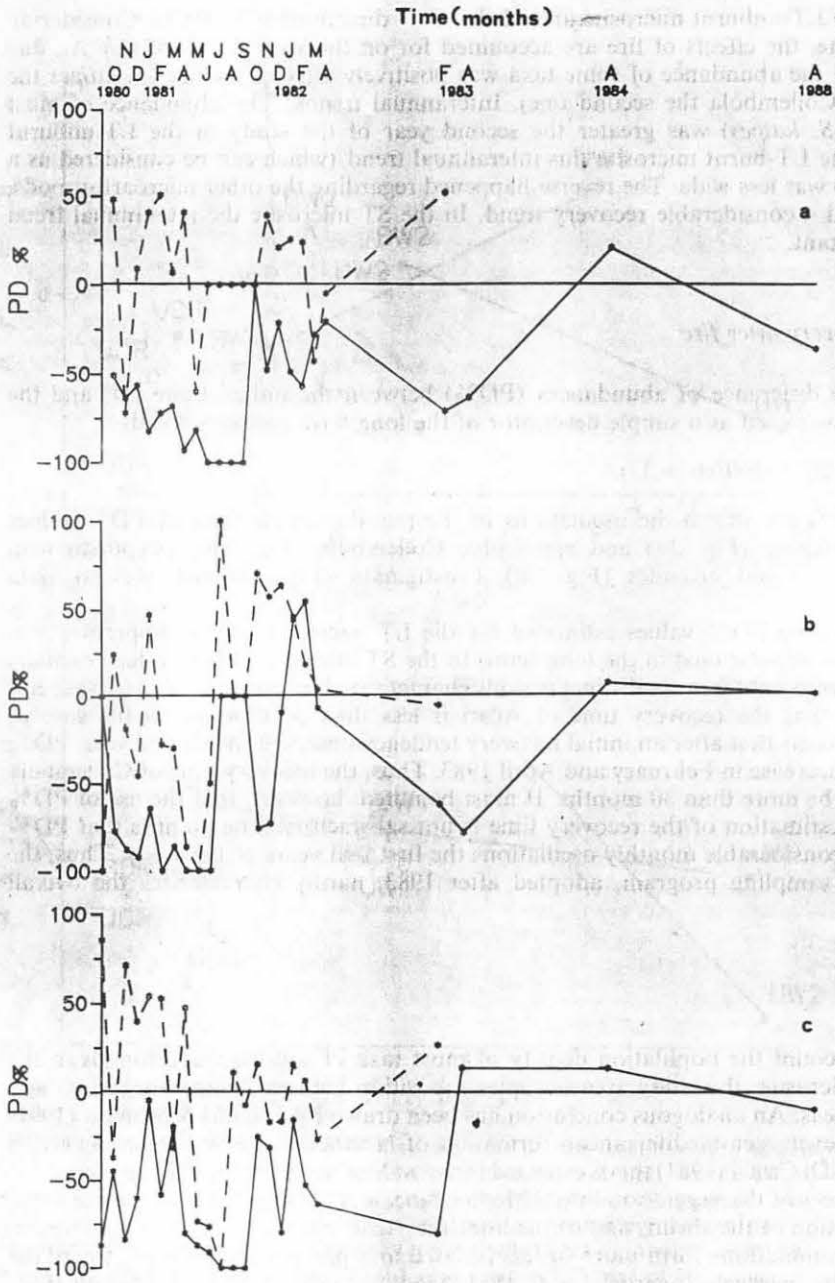

Fig. 3a–c

layer of the soil (Pande & Berthet 1975, Usher 1975, Mitchell 1978 among others) and their density and diversity depends on the structural diversity of this habitat (Anderson 1978). To an extent, the effects of the fire can be explained and predicted by the above relationships. The fire resulted in a less heterogeneous, less divided environment for microarthropods, and the seasonal as well as the between microsites variations of their abundances were accordingly reduced. The first post fire year the abundance of most

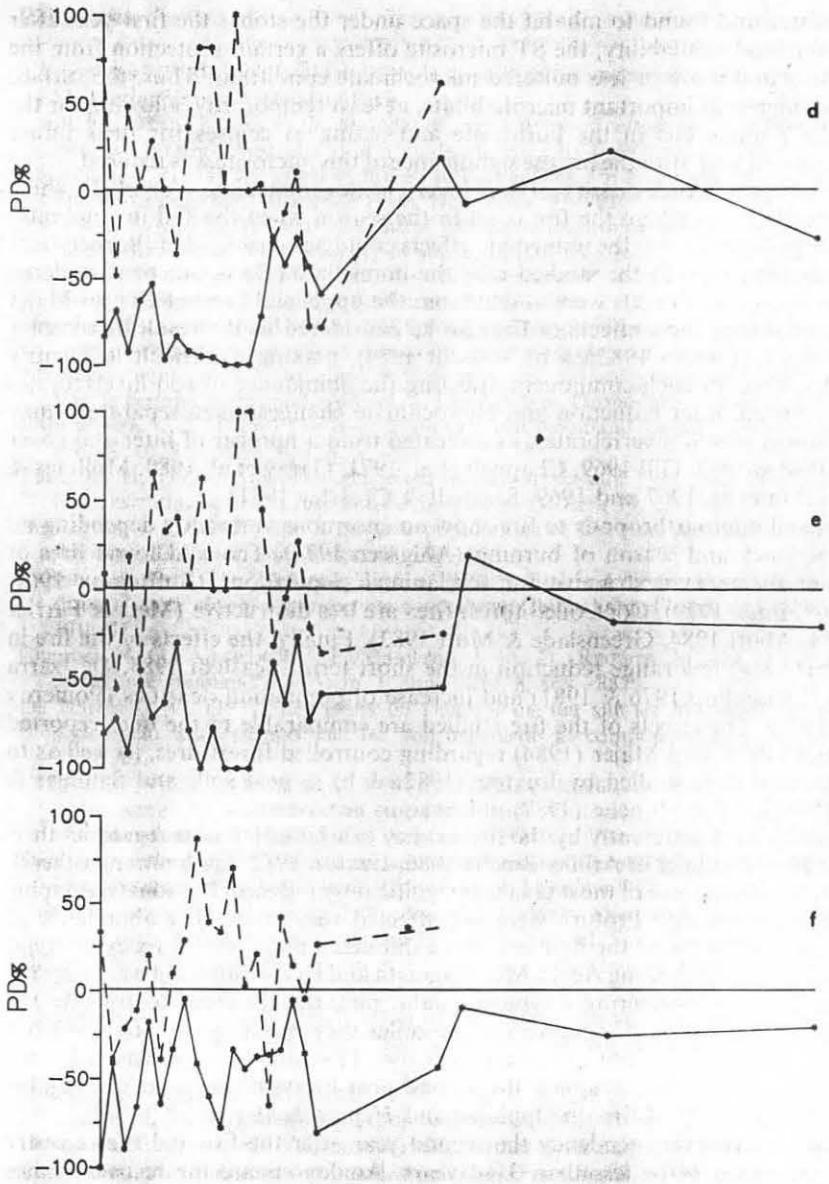

Fig. 3a–f. Monthly variations of the percentage difference (PD%) of microarthropod abundance between sites (Burnt & Unburnt) and for each microsite separately (Litter = solid, line, Stones = dashed line). Negative PD% values indicate a reduction in abundance due to fire. a) Euedaphic Collembola, b) Epiedaphic Collembola, c) Cryptostigmata Matures, d) Cryptostigmata Juveniles, e) Mesostigmata, f) Prosigmata.

microarthropods was reduced to the levels recorded normally under stones (result of C.V.A.) and the between microsites variation in the burnt site was minimized. Thus, we could suggest that only the euedaphic portion of the populations resisted the fire. This is also reported by Metz & Farrier (1973), Majer (1984) and Saulnier & Athias-Binche (1986). However, in the study area certain populations exhibited a plasticity regarding their habitat requirements. The more obvious examples were *S. latipes* and some Collembola recorded

normally in the litter and found to inhabit the space under the stones the first year after the fire. Except for food availability, the ST microsite offers a certain protection from the direct sun radiation and more or less buffered microclimate conditions. Thus, the surface stones can be considered as important microhabitats, at least temporarily, allowing for the persistence of the populations in the burnt site and acting as centres for their future restoration. The second year after the fire the significance of this microsite was reduced.

Fire may affect the population density of soil invertebrates immediately or in the short and the long term. In cases where the fire is set in the season when the soil invertebrates are active in the organic horizons, the immediate effects could be considerable (Bornemissza 1969, Metz & Farrier 1973). In the studied case the immediate effects can be considered less important as most soil animals were absent from the upper soil layers (see also Majer 1984). The short and long term effects of fire can be considered as the result of complex microhabitat changes (Luxton 1982a & b, Seastedt 1984), making it difficult to identify the relative contribution of each component affecting the abundance of soil invertebrates (Seastedt 1984). Indeed, litter reduction and microclimate changes taken separately, may affect the abundances of soil invertebrates, as indicated from a number of litter and cover manipulations (Pearse 1943, Gill 1969, Chappell et al. 1971, Garay et al. 1980, Molfetas & Blandin 1980, Huhta et al. 1967 and 1969, Seastedt & Crossley 1981).

The responses of soil microarthropods to fire show an enormous variability depending on the intensity, frequency and season of burning (Ahlgreen 1974). The wild forest fires of high intensity are the most destructive for soil animal populations (Buffington 1967, Bornemissza 1969, Buck 1979). Controlled forest fires are less destructive (Metz & Farrier 1973, Majer 1984, Abott 1984, Greenslade & Mott 1983). Finally, the effects of the fire in non forested areas vary: low range reduction in the short term (Seastedt 1984, De Izarra 1977), no effect (Lussenhop 1976 & 1981) and increase of population densities (Pomeroy & Rwakaikara 1975). The effects of the fire studied are comparable to the ones reported by Metz & Farrier (1973) and Majer (1984) regarding controlled forest fires, as well as to the effects of the wild fires studied by Luxton (1982a & b) in peat soils and Saulnier & Athias-Binche (1986), Athias-Binche (1987) in a maquis ecosystem.

Different taxa are affected differently by the fire or they exhibit differences regarding their recovery (Majer 1984, Saulnier & Athias-Binche 1986, Luxton 1982 a & b among others). In the study area, the abundance of most taxa was significantly reduced, but some euedaphic animals such as Symphyla and Protura were not affected very much. The abundance of Collembola was severely reduced the first year but exhibited a considerable recovery trend the second year of the study. Among Acari, Mesostigmata and Cryptostigmata were affected more than Prostigmata. Considering Cryptostigmata, matures appeared to tolerate the immediate effects of the fire but the number of juveniles they produced the first post fire year was very low compared to that of the unburnt site. This might be the reason for the low abundance of mature Cryptostigmata the second post fire year and consequently for the apparently delayed effect of fire on Oppiidae and *Hypochthonius* sp.

Most taxa exhibited a recovery tendency the second year after the fire and the recovery time is roughly estimated to be less than 3–4 years. Analogous are the recovery times estimated by Metz & Farrier (1973), Majer (1984) and Seastedt (1984). On the other hand, Huhta et al. (1979) and Bornemissza (1979) reported that several years after intense fires, there were no signs of Cryptostigmata recovery. In general, the recovery of soil animal populations depends on the recovery of the vegetation and the litter layer which in phrygana seems to be a rather quick process (Arianoutsou-Faraggitaki 1984).

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References

Anonymous (1963) Etude ecologique de la zone Mediterranneenne. Carte Biocolimatique de la zone Mediterranneenne. UNESCO Paris.

Abott, I. (1984) Changes in the abundance and activity of certain soil and litter fauna in the Jarrah forest of Western Australia after a moderate intensity fire. Aust. J. Soil Res. **22**, 463–469.

Ahlgren, I. F. (1974) The effect of fire on soil organisms. In: Kozlowski, T. T., Ahlgren, C. E. (eds.) Fire and Ecosystem. Academic Press, New York, 47–72.

Anderson, J. M. (1978) Inter- and intra- habitat relationships between Woodland Cryptostigmata species diversity and the diversity of soil and litter microhabitats. Oecologia **32**, 341–348.

Arianoutsou-Faraggitaki, M. (1984) Post-fire successional recovery of a Phryganic (East Mediterranean) ecosystem. Oecologia Plantarum **5**, 387–394.

Asikidis, M. D., Stamou, G. P. (1991) Spatial and temporal patterns of an oribatid mite community in an evergreen-sclerophyllous formation (Hortiatis, Greece). Pedobiologia **35**, 53–63.

Athias-Binche, F. (1987) Modalites de la cicatrisation des ecosystems mediterraneens apres incendie: Cas de certains arthropodes du sol. 3. Les Acariens Uropodides. Vie Milieu **37**, 39–52.

Bornemissza, G. F. (1969) The re-invasion of burnt woodland areas by insects and mites (Abstract). Proc. Ecol. Soc. Aust. **4**, 138.

Buck, C. H. (1979) Auswirkungen eines Waldbrandes auf Tiere und Pflanzen unter besonderer Berücksichtigung der Mäuse und Arthropoden. Drosera **79**, 63–80.

Buffington, J. D. (1967) Soil arthropod populations of the New Jersey pine barrens as affected by fire. Ann. Entomol. Soc. Amer. **60**, 530–535.

Cepeda-Pizarro, J. G., Whitford, W. G. (1989) Spatial and temporal variability of higher microarthropod taxa along a transect in a northern Chihuahuan Desert watershed. Pedobiologia **33**, 101–111.

Chappel, H. G., Ainsworth, J. F., Cameron, R. A. D., Redfern, M. (1971) The effect of trampling on a chalk grassland ecosystem. J. appl. Ecol. **8**, 869–882.

De Izarra, D. C. (1977) Les effets de l'emploi du feu sur les Microarthropodes du sol dans la region semi-aride pampeenne. In: Soil organisms as components of ecosystems. Ecol. Bull. **25**, 357–365.

Di Castri, F, Vitali – Di Castri, V. (1981) Soil fauna of Mediterranean-climate regions. In: Ecosystems of the world. II. Mediterranean-type Shrublands. Di Castri F., Goodall, F., Specht, R. L. (eds). Elsevier scientific Publishing Co. Amsterdam, Oxford, New York. 445–478.

Diamantopoulos, I. (1983) [Structure and distribution of Greek Phyganic ecosystems]. (In Greek with English summary). Ph D Thesis, University of Thessaloniki.

Garay, I., Cancela Da Fonseca, J. P., Blandin, P. (1980) The effects of trampling on the fauna of a forest floor. I. Microarthropods. In: Proc. 7th Int. Col. Soil Zool. Syracuse U.S.A. 200–212.

Gill, R. W. (1969) Soil microarthropod abundance following old-field litter manipulation. Ecology **50**, 805–816.

Greenslade, P., Mott, J. J. (1983) Effect of fire on invertebrates in an Australian tropical grassland. In: New Trends in Soil Biology. Proc. VIII. Inter. Coll. of Soil Zool. Louvain la Neuve (Belgium). 635–637.

Huhta, V., Karppinen, E., Nurminen M., Valpas, A. (1967) Effect of silvicultural practices upon arthropod, annelid and nematode populations in coniferous forest soil. Ann. Zool. Fenn. **4**, 87–145.

Huhta, V., Nurminen, M., Valpas, A. (1969) Further notes on the effect of silvicultural practices upon the fauna of coniferous forest soil. Ann. Zool. Fenn. **6**, 327–334.

Kaneko, N. (1985) A comparison of oribatid mite communities in two different soil types in a cool temperate forest in Japan. Pedobiologia **28**, 255–264.

Lussenhop, J. (1976) Soil Arthropod response to prairie burning. Ecology **57**, 88–98.

Lussenhop, J. (1981) Microbial and microarthropod detrital processing in a prairie soil. Ecology **62**, 964–972.

Luxton, M. (1982a) Studies on the invertebrate fauna of New Zealand peat soils. I. General survey of the sites. Rev. Ecol. Biol. Sol **19**, 535–552.

Luxton, M. (1982b) Studies on the invertebrate fauna of New Zealand peat soils. II. Restiad peats. Rev. Ecol. Biol. Sol **19**, 553–578.

Magioris, S. N. (1989) The arthropod fauna of the soil on the island of Ikaria – Aegean sea- Greece. Biol. Gallohellenica **15**, 153–158.

Majer, J. D. (1984) Short term responses of soil and litter invertebrates to a cool autumn burn in Jarrah *(Eucalyptus marginata)* forest in Western Australia. Pedobiologia **26**, 229–247.

Margaris, N. S., Vokou, D. (1982) Structural and physiological features of woody plants in phryganic ecosystems related to adaptive mechanisms. Ecol. Mediterranea **8**, 449–459.
Metz, L. J., Farrier, M. H. (1973) Prescribed burning and populations of soil mesofauna. Environ. Entomol. **2**, 433–440.
Mitchell, M. J. (1978) Vertical and horizontal distributions of oribatid mites (Acari: Cryptostigmata) in an aspen woodland soil. Ecology **59**, 516–525.
Molfetas, S., Blandin, P. (1980) The effects of trampling on the fauna of a forest floor. II. Macroarthropods. In: Proc. 7th Int. Col. Soil Zool., Syracuse USA. 213–225.
Papanastasis, V. P. (1977) Fire ecology and management of phrygana communities in Greece. In: Mooney, H. A., Conrad, C. E. (eds), Proc. Symp. on the environmental consequences of fire and fuel management in Mediterranean ecosystems. U.S.A.D. Forest service, Washington. 476–482.
Pande, Y. D., Berthet, P. (1975). Observations on the vertical distribution of soil Oribatei in a woodland soil. Trans. R. ent. Soc. Lond. **127**, 259–275.
Pearse, A. S. (1943) Effects of burning-over and raking-off litter on certain soil animals in the Duke forest. Amer. Midland Naturalist **29**, 406–424.
Petersen, H. Luxton, M. (1982) A comparative analysis of soil fauna populations and their role in decomposition processes. 4. Structure and size of soil animal populations. Oikos **39**, 306–329.
Pomeroy, D. E., Rwakaikara, D. (1975). Soil arthropods in relation to grassland burning. E. Afr. agric. For. J. **41**, 114–118.
Saulnier, L., Athias-Binche, F. (1986) Modalites de la cicatrisation des ecosystemes mediterraneens apres incendie: Cas de certains arthropodes du sol. 2. Les Myriapodes edaphiques. Vie Milieu **36**, 191–204.
Seastedt, T. R. (1984) Microarthropods of burned and unburned tallgrass prairie. J. Kansas Entomol. Soc. **57**, 468–476.
Seastedt, T. R., Crossley Jr., D. A. (1981) Microarthropod response following cable logging and clear – cutting in the Southern Appalachians. Ecology **62**, 126–135.
Sharma, A. P., Bisht, J. S., Singh, J. S. (1984) Microarthropods associated with certain litter species in Kumann Himalaya. Pedobiologia **27**, 222–236.
Sgardelis, S., Stamou, G., Margaris, N. S. (1981) Structure and spatial distribution of soil Arthropods in a phryganic (East Mediterranean) ecosystem. Rev. Ecol. Biol. Sol **18**, 221–230.
Usher, M. B. (1975) Aggregation responses of soil arthropods in relation to the soil environment. In: Anderson, M. J., Macfadyen, A. (eds), The role of terrestrial and aquatic organisms in decomposition processes. Blackwell Scientific Publications. 61–94.